DOI: 10.53469/jtpes.2024.04(01).04

Design of a New Glass Cleaning Robot

Haoyu Jiang

Nanhai Middle School, Shenzhen 518000, Guangdong, China
68348580@qq.com

Abstract: ***Improve the various abilities of glass cleaning robots, such as climbing ability and obstacle crossing ability at any angle, change the traditional movement mode of robots, and enable them to perform obstacle free movement in three-dimensional space. Taking inspiration from the quadruped movement of geckos, the UG software in mechanical CAD/CAM is used to simulate the structure of a glass cleaning robot for gait planning and structural design. By studying the force situation, the dimensions of the four bar mechanism and the size of the suction cup of the vacuum suction cup quadruped glass cleaning robot were derived. The structural design diagram was drawn, and its operating trajectory and mode were explained. Create post-processing through Postbuilder, conduct comprehensive testing and simulation to ensure accuracy before processing its components. The calculation shows that the thigh step distance within one cycle is 89.83 mm, and the calf step distance is 3.11 mm. So, the total step distance of a single leg in one cycle is 92.94 mm. Based on this, a top-down modeling approach was adopted, and assembly methods, connection methods, and driving methods were set in the simulation. The cosine function was used to control the motion trajectory of the legs. This design effectively simulates the motion of geckos. In future research, we will continue to focus on the dynamic trajectory of the robot's tail, in order to enable the robot to adjust its posture through its tail under microgravity and make the motion of the gecko like robot more flexible.***

Keywords: Glass cleaning robot, Motion simulation, CAD/CAM.

1. INTRODUCTION

With the progress of modern technology, the optimization of people's living environment, and the improvement of work quality, various auxiliary robots are increasingly being used in various industries, and people's requirements for robots are gradually increasing. Animal survival has evolved special motor functions and sensitive forms of movement, such as wild leopards, frogs, spiders, etc., which have become creative sources for researching intelligent robots, thereby creating more powerful glass cleaning robots.

The foot mechanism of the glass cleaning robot has strong motion ability, with many advantages such as high degrees of freedom, flexible movement, strong adaptability, simple structure, and diverse motion modes. Among them, foot robots that can perform obstacle free movements in three-dimensional space have good application prospects. In 2018, American scientist Keller Autumn studied the adsorption capacity of geckos and found that up to 500000 fine hairs on the soles of geckos generate intermolecular forces with the surface of objects, ranging in thickness from tens of nanometers to a few micrometers. The gecko's toes are long and flat, with a small plate covering the flesh pad on the toes. There are hairy protrusions on the plate in sequence, and the end is forked. These invisible small "hooks" allow geckos to adhere to irregular surfaces, similar to the widely used tear off adhesive seamless Velcro. The main adsorption methods of glass cleaning robots include magnetic suction, dry adhesion, and suction cup type. Magnetic suction is only suitable for movement on magnetic surfaces, with significant limitations on the motion scenario; Dry adhesion has the advantages of simple adhesion process, no noise, reusability, and wide application range, but it has high material cost and difficult maintenance. From the perspective of indoor use scenarios mostly consisting of smooth surfaces such as glass and ceramic tiles, this solution adopts a suction cup vacuum adsorption method. The advantages are that it can overcome small obstacles, mature technology, convenient purchase and maintenance of standard parts, low cost, and easy promotion.

2. ROBOT PLANNING

The working plane of the robot designed in this article is a relatively smooth horizontal surface, such as ceramic tiles, glass, and other surfaces. The motion mechanism of this type of gecko like robot can be directly applied to the operation design of household glass cleaning robots, which has broad application prospects and is in line with the current development trend of smart homes. The appearance and structure of glass cleaning robots are similar, with the main movement core being the leg structure, so the leg structure design is the key to the overall structural design. The key points of leg structure design are that it can achieve a predetermined trajectory, move forward and turn, lift the feet to an appropriate height, ensure stability of movement, and meet the requirements of strength and stiffness. After a comprehensive comparison between the mobile and adsorption methods, a suction cup type was selected for the adsorption method, with TPE material used as the suction cup material and electrical drive used as the driving method. TPE has the advantages of convenient processing and wide processing methods for ordinary plastics, as well as excellent characteristics such as high elasticity, aging resistance, and oil resistance. At present, the appearance of most glass cleaning robots is square or rectangular, with suction cups on all four legs for vacuum adsorption, but there is no lifting action. When reaching the edge of frameless glass, it is easy to have insufficient air pressure and the robot is trapped. The robot will sound an alarm due to insufficient air pressure and cannot move on its own. It must be manually operated to stop the adsorption before the robot can be removed. If the trapped position is in a high place or a narrow gap that is difficult for users to reach, the robot is prone to getting stuck and unable to move, affecting the user experience. The edge obstacle detection function of robots is still not perfect, but if a gecko like leg structure is adopted, it can perfectly avoid obstacles, move more flexibly, and have more diverse usage scenarios. The quadruped of the gecko like robot is driven by pneumatic force, which is compliant and can prevent excessive force from damaging the surface of objects.

Through research on geckos, it has been found that the structure of their limbs has a significant impact on their mobility, and the muscle movements at their joints are closely related to their main body movements, serving as the foundation of their movement. The gecko skeleton structure modeled based on this mainly consists of four legs and a body, as shown in Figure 1. The four legs have the same structure and are symmetrically distributed. Thigh a and calf b have one degree of freedom (rotating pair 13, 23, 33, 43 respectively), while legs are connected to body c and have two degrees of freedom to rotate (such as the 11 and 12 of the upper left leg). The foot of the gecko like robot is a four bar mechanism, and the operation of the four bar mechanism needs to be verified during design. The three-dimensional movement of geckos is related to their crawling environment. When crawling on the ground, the distance between the feet and the abdomen is large. When on a vertical wall or even negative surface, the leg joints retract, and the distance between the feet and the abdomen is small, similar to the normal walking and lying posture of pets. The latter can effectively reduce torque by reducing distance, improving crawling reliability. Therefore, rotation pairs are set at positions 12, 22, 32, and 42 of the gecko like robot to control the longitudinal rotation of the robot's four legs and change the height of the robot's body c from the ground.

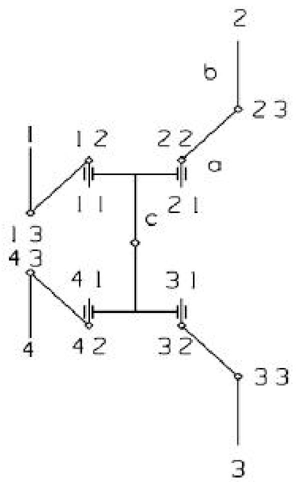


Figure 1: Structure of the skeleton model of the glass cleaning robot

The glass cleaning robot completes continuous movement through the cyclic motion of the quadruped mechanism, and the movement pattern of each leg is called gait. Through the study of geckos, it can be found that they mainly have two modes of movement, namely diagonal mode and triangular mode. The gecko moves at a relatively constant speed with each step, reducing the difficulty of robot biomimetics. The quadruped gecko robot is symmetrically distributed and moves in a diagonal pattern, where the two legs on the diagonal move while the other leg on the diagonal adsorbs support, completing one movement cycle twice. This solution shortens the movement cycle, the robot crawls faster, and diagonal gait control is also more convenient and flexible. When starting, legs 2 and 4 adhere to the wall, while legs 1 and 3 are in a suspended state; Legs 1 and 3 move forward through motor drive and adhere to the wall surface; Suspend legs 2 and 4 in the air and move forward; Legs 2 and 4 adhere to the wall. At this point, complete a motion cycle and repeat the process continuously to perform linear motion, which is driven by three motors together. This plan can be linked with visual detection devices to avoid some obstacles and achieve flexible turning in the future.

The four legs (i.e. 1, 2, 3, 4) are connected to vacuum suction cups, which are one of the actuators of vacuum equipment. The use of vacuum suction cups to grab items is low-cost. Connect the suction cup to the vacuum equipment through a connecting pipe, then make contact with the surface, start the equipment to suction, generate negative pressure, and adhere to the surface. After the diagonal legs have completed displacement, they are then smoothly inflated into the vacuum suction cup, causing negative air pressure to become zero or slightly positive, thereby detaching from the surface.

Calculate the diameter of the circular suction cup according to the following equation:

$$D = \sqrt{\frac{1000mgk}{\pi np}} \tag{1}$$

In the formula, D is the suction cup diameter, in millimeters; M is the mass of the robot, in kilograms; G is the gravitational acceleration, 9.8; K is the safety factor, taken as 4-8; N is the number of working suction cups; P is the vacuum pressure, in kPa.

The estimated weight of the robot is 9kg, with a safety factor of 4, 2 working suction cups, and a vacuum pressure of 90kPa. By inputting the data, it can be concluded that:

$$D = \sqrt{\frac{1000*9*9.8*4}{\pi*2*90}}=25mm \tag{2}$$

The application of the gecko like robot is mainly focused on the legs, and there are driving motors at the joints of the legs. The joint can be set as a pin connection, and the motor is driven by position using cosine function to control the motion state. g is the walking distance of the legs, calculated as follows:

$$q = A * \cos(360^{o}\frac{t}{T} + B) + C \tag{3}$$

In the formula, A is the amplitude, in millimeters; B is the phase, in units of o; C is the offset, in millimeters; T is the period, s; T is time, in seconds.

The leg movement control parameters can be set to t=40s, T=40s, B=0^{o}, C=0.

The distance between the thighs is: $2 * l_1 * \cos\frac{a_1}{2} = 2 * 47.8 * \cos 20^{o} = 89.83mm$

The leg step distance is:

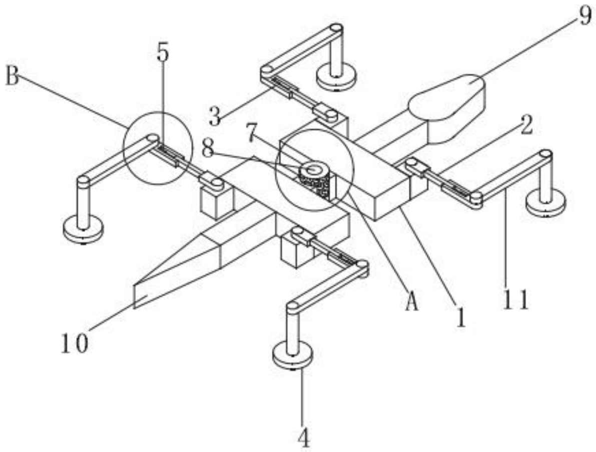
$$l_2 * [sin(90^{o} - \frac{a_1}{2} + \frac{a_2}{2}) - sin(90^{o} - \frac{a_1}{2})] = 55 * [sin85^{o} - sin70^{o}] = 3.11mm$$

In the formula, is the effective rotational length of the thigh, in millimeters; Is the effective length of rotation of the calf, in millimeters; Is the angle of thigh swing, in units of o; Is the angle of leg swing, in units of o.

So, the total step distance of a single leg in one cycle is 92.94mm.

3. STRUCTURE DESIGN

Geckos have excellent climbing ability on any surface, and the adhesive force required for their stable crawling comes from the intermolecular forces formed between the foot bristles and the contact surface. Most existing gecko like robots based on dry adhesion technology only achieve adhesion and crawling on vertical surfaces. Therefore, achieving stable adhesion motion of robots on the ceiling is an important link and technical difficulty for glass cleaning robots to simulate the unobstructed movement of geckos on three-dimensional surfaces. Developing a gecko like robot that can stably adhere to negative surfaces, enabling the robot to have three-dimensional space surface unobstructed motion capabilities, has important practical significance and application value in anti-terrorism reconnaissance, narrow space detection, spacecraft surface in orbit maintenance, and other fields. The structure of the gecko like quadruped robot designed based on this is shown in Figure 2.



1. Connection block; 2. The first movable pole; 3. Sliding sleeve; 4. Suction cup sole; 5. Electric telescopic rod; 6. Chutes; 7 snap rings; 8. Card block; 9. Head; 10. Tail; 11. Second movable pole.

Figure 2: Robot Structure Design

This glass cleaning robot consists of four parts: body, four legs, head, and tail. The body is composed of two connecting blocks 1 that are connected to each other, each of which is equipped with a first movable rod 2 that can rotate relative to each other. A sliding sleeve 3 is installed by sliding through a linear driving element, and one end away from the first movable rod 2 is connected to the second movable rod 11 by rotating. The other end away from the sliding sleeve 3 is equipped with a suction cup foot 4. The linear driving component includes an electric telescopic rod 5, and a sliding groove 6 is opened along its sliding direction on the sliding sleeve 3. The first movable rod 2 is slidably installed inside the sliding groove 6, and the two ends of the electric telescopic rod 5 are respectively connected to the first movable rod 2 and the sliding groove 6. The two connecting blocks 1 are respectively equipped with a snap ring 7 and a snap block 8 at one end that are close to each other. The snap block 8 is horizontally rotated and connected within the snap ring 7, and there is a driving component on the snap ring 7 that drives the rotation of the snap block 8. The two connecting blocks 1 are detachably connected to the head 9 and tail 10 on the side away from each other, and the suction cup foot 4 and the second movable rod 11 can also be detachably connected.

4. MOTION SIMULATION

CAD/CAM refers to computer-aided design and computer-aided manufacturing, which are currently the mainstream design and manufacturing methods in the context of the rapid development of electronic information technology and CNC machining technology. Choosing appropriate software for simulation processing simulation can greatly improve design efficiency. The mechanical CAD/CAM software used in the design of the glass cleaning robot in this article is Unigraphics NX (UG) software produced by Siemens PLM Software. This software is powerful and can easily construct various complex entities and shapes. It is currently the mainstream design simulation software in the engineering industry. After using the parameters provided by the software to draw the three-dimensional appearance of the robot, the data can be directly imported into the simulation software to verify the design parameters. Utilize the CAM function of UG software Postbuilder to create post-processing, conduct comprehensive testing and simulation first, and ensure accuracy before processing its components. The Post post-processor is convenient to use and can directly extract information from the tool path of the part for post-processing, without generating the original tool position file like graphic post-processing. UG is one of the most common mechanical CAD/CAM software. Proficient use of UG software can provide people with a clearer understanding of gait planning and motion simulation for gecko like robots.

There are many components in the glass cleaning robot, and many part sizes need to be referenced to each other. A top-down modeling approach can be adopted, which is to first model in the final assembly drawing and then establish models for each component. The modeling steps are as follows: after performing 3 "stretching" operations, click "mirror", select the FRONT plane as the mirror plane, and finally click "OK" to complete the modeling of the body connection part. The connection between the body and legs, with the right protruding part connected to the concave hole of the body connection, is an interference fit to ensure a tight connection. The thighs and calves can be simplified as linkage mechanisms, and the soles of the feet are suction cup type. The above fixed parts are assembled as usual, and the leg moving parts need to be connected to the mechanism. Click "Assembly", select the parts to be assembled, select "Pin" connection, click "Placement", define "Axis Alignment", "Translation", "Rotation" in sequence, click "OK" to complete the mechanism connection assembly. Assemble other parts in the same way. Click on "Electric Motor" and select "Add Electric Motor" to add the defined electric motor. Then click "Run", and the robot assembly diagram is shown in Figure 3.

Figure 3: Robot assembly diagram

5. CONCLUSION

This article establishes a three-dimensional model of a robot based on the biological skeleton model of a gecko. The leg joints of the gecko are simulated through multi degree of freedom connections, and micro motors are set at the connections to drive joint movement, thereby driving the entire leg to lift and translate, achieving the walking of the robot. The motion simulation module can be used in UG software to simulate the motion of a gecko like robot. The assembly method, connection method, and driving method are set in the simulation, and the cosine function is used to control the movement trajectory of the legs. The step distance data is calculated, which well simulates the motion of the gecko.

In the household field, the mechanism of gecko like robots can be combined with existing glass cleaning robots. At present, a common window contains at least one pair of flat or sliding glass. If it is a closed balcony or sunroom, the number of adjacent glass pieces can reach several or more than ten. However, the existing glass cleaning robot has a single movement method and cannot achieve the movement of crossing the window frame. The operator needs to manually control it by pressing a button to turn off the air pump and eliminate suction. After replacing a piece of glass, press the button again to start the air pump and generate suction. If the glass is at a high place, the operator must use auxiliary tools such as ladders to make movement more difficult. Depending on the size, the cleaning time for a single piece of glass is usually several tens of seconds to a few minutes, and then a voice reminder will appear to stop working, requiring manual replacement of the position. During operation, the glass cleaning robot requires the assistance of an operator to move the position at all times. The automated cleaning of a single piece of glass must be combined with manual assistance across the glass, which does not completely liberate manpower and still requires the full participation of the operator, making it impossible to fully automate. The ideal window cleaning robot starts the program and automatically operates after adsorbing glass. It is currently impossible for the operator to leave the site, even if the operator can sit down and rest while cleaning a single piece of glass. If the robot is not moved in time after completing the cleaning work, it will remain stationary for a long time.

The gecko like robot has a higher degree of freedom compared to the current glass cleaning robot, which has four fixed vertices with square or rectangular legs. After combining the two, combined with the running trajectory algorithm, the window cleaning robot can lift its four legs, "cross" the glass frame, and complete its own flipping operation after completing the cleaning of a single piece of glass. Another limitation of the current window cleaning robot is its working angle limitation, which allows it to operate on a glass surface that is perpendicular to 90 degrees. However, if the inclination angle continues to increase until it reaches a ceiling that is tilted at -180 degrees, it will not work. But geckos can freely crawl upside down on the top of houses, and their four legged and tail bristles can provide sufficient adsorption force. Compared to the weight and volume of geckos, their four legged and tail areas are limited, and their adsorption capacity is strong. Currently, ordinary suction cups still cannot provide reliable adsorption force. Therefore, in addition to gait planning, it can be combined with materials science to improve the suction cup structure, changing from a flat suction cup to a ball valve shaped suction cup or imitating a bristle shaped suction cup, enhancing adsorption capacity and making its suction force greater and more reliable. The improvement of this material can further enhance the terrain adaptability of the gecko like robot in operating scenarios. The suction cup quadruped is suitable for smooth surfaces such as glass and tiles, while the bristle quadruped can be extended to move on ordinary walls, ultimately achieving full space surface adhesion motion.

This study focuses on the quadruped movement mechanism of gecko like robots. The tail of geckos may appear long pointed, short blunt, or even spherical, but currently, the tail in the robot drawings does not have actual movement and only serves as a decoration. In the observation and research of the biological gecko, it is known that the gecko's tail actually serves as the fifth "leg", which is of great significance for adhering to surfaces, supporting body turning, and so on. In future research, we will continue to focus on the dynamic trajectory of the tail, in order to enable the robot to adjust its posture through its tail under microgravity and make the motion of the gecko like robot more flexible. By analyzing the current research status and the development of key technologies, this study believes that gecko like robots have broad prospects in applications such as smart homes and cutting-edge technology, and have a good future development trend.

REFERENCES

[1] Z.W. Yu, Gecko like robot technology [M] Beijing: Beijing Institute of Technology Press, 2021.
[2] W.H. He, Design and simulation of suction cup negative pressure quadruped wall climbing robot [J]. Robotics Technology and Applications, 2017 (3): 43-45.
[3] D. Li, Structural Design and Kinematic Analysis of Gecko like Robots [J]. Science and Technology Innovation 2019 (13): 79-80.
[4] Z.Y. Wang, Research on the Adhesion Performance of Gecko Robot Feet and Design of Adhesion and Detachment Trajectory under Simulated Microgravity Science Bulletin, 2017, 62 (19): 2149-2156.
[5] Y. Fu, Research on the motion control system of a gecko like agricultural information collection robot [J] Research on Agricultural Mechanization, 2017, 39 (1): 96-100.